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Journal Article

Concentration and Size of Asbestos in Water Supplies

by James R. Millette,* Patrick J. Clark,*† Michael F. Pansing,* and James D. Twyman*

A review of the results of over 1500 asbestos analyses from U.S. water supplies suggests that the majority of water consumers are not exposed to asbestos concentrations in their drinking water over 1×10^6 fibers per liter. There are, however, somepopulations that are exposed to waterborne asbestos concentrations over 10×10^6 fibers per liter caused by natural erosion, mine processing wastes, waste pile erosion, corrosion of asbestos cement pipe, or disintegration of asbestos tile roofs running into cisterns. The distribution of fiber sizes in the water is dependent on the source of the fibers. The average length of chrysotile fibers found in an asbestos cement distribution system was 4 μm, while the average fiber length of chrysotile fibers contributed to a water supply by natural erosion was 1 μm.

Fiber Concentrations in Water

Drinking water is contaminated by asbestos fibers from pollution, geologic erosion, and the disintegration of asbestos cement pipe. Since 1973-74 when asbestos was first reported to be present in potable water supplies (*1-4*), a number of laboratories have been analyzing for asbestos in drinking water in various cities of the United States. A review of the results of over 1500 water samples analyzed for asbestos by electron microscopy suggests that several populations of U.S. water consumers have been exposed to significant numbers of asbestos fibers in their drinking water at some time.

The waste discharge from the processing of iron ore has contributed amphibole fibers to the areas of Lake Superior which supply water for the cities of Duluth, Two Harbors and Beaver Bay, Minnesota. Concentrations as high as 600×10^6 fibers/l. have been reported for Duluth water (*5*). Fiber counts as high as 200×10^6 and 92×10^6 fibers/l. have been reported for Two Harbors and Beaver Bay, respectively. The erosion of an old asbestos waste pile is suspected to have contaminated a water supply in Kentucky with as much as 74×10^6 fibers/l. of chrysotile asbestos. Natural erosion of asbestos bearing rock formations is considered to be the source of fibers in some water supplies of the area around San Francisco, California and in supplies near Seattle, Washington. Concentrations of chrysotile asbestos between 1 and 100×10^6 fibers/l. have been reported for a number of supplies around San Francisco and over 100×10^6 chrysotile fibers/l. have been found consistently in the water supply of Everett, Washington. One sample of water from a distribution system in South Carolina collected after a length of asbestos cement pipe which had been attacked by corrosive water contained over 500×10^6 chrysotile fibers/l. Drinking water in other asbestos cement pipe distribution systems in Florida, Kentucky, and Pennsylvania have been shown to contain concentrations of chrysotile asbestos over 10×10^6 fibers/l. In tap water drawn from cisterns using asbestos tile roofing materials for rain collection, concentrations of chrysotile asbestos over 500×10^6 fibers/l. have been found.

Table 1 summarizes the distribution of reported asbestos concentrations in the drinking water of various cities in the United States. The table is based on available results from transmission electron microscopy analyses. Because the data were re-

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ported by 15 different laboratories, some using different sample preparation methods, there are some disagreements over actual values. However, Table 1 suggests that asbestos is a contaminant in a significant number of U.S. water supplies. A listing of the data available on asbestos in water supplies is presented in Table 2.

Industrial discharges of asbestos were found to range from 10^6 to 10^{12} fibers/l. during an EPA-sponsored survey (*7*). With the exception of the Lake Superior situation, however, it has not been shown conclusively that any discharged asbestos fibers make their way into public drinking water.

Chrysotile, a serpentine mineral, is the most common asbestos variety found in water supplies, but some amphiboles have been identified. The amphibole crocidolite, a minor constituent of asbestos cement pipe, has been found along wth chrysotile in some waters distributed through the pipe. The amphibole fibers in Lake Superior have been determined to be primarily of the cummingtonite-grunerite series of which amosite, a commercial form of asbestos, is a member. There is still some debate among mineralogists as to whether amphibole fibers found in the lake water should be called asbestos fibers or cleavage fragments. Amphiboles of the tremolite-actinolite series have been found in some water supplies of the Pacific Northwest. No fibers of the asbestos variety anthrophyllite have been reported in drinking water.

Asbestos fibers in the source of a water supply can be controlled by filtration. Treatment plants in operation in Duluth and Two Harbors, Minnesota, and pilot filtration plants in Seattle and Everett, Washington, have shown that both amphibole and chrysotile fibers can be eliminated from the water supply by coagulation and filtration.

While it is estimated that some 200,000 miles of asbestos cement pipe are in use in the United States (*17*), reported analyses suggest that most asbestos cement pipe does not shed significant numbers of fibers into the water. The quality of water transported is known to be a critical parameter in the release of fibers from the pipe. The corrosive effect of water on asbestos cement pipe has been described by the aggressiveness index (AI):

$$AI = pH + \log (AH)$$

where pH is the index of acidity or alkalinity of the water in standard pH units, A is the total alkalinity (in mg/l.) as $CaCO_3$, and H is the calcium hardness (in mg/l.) as $CaCO_3$. Higher values of this aggressiveness index are less corrosive than lower values. Water with an AI less than 10 is considered very aggressive to many types of pipe, while AI values greater than 12 are considered essentially non-aggressive. A statistical sampling performed by our laboratory of water supplies representative of the utilities throughout the United States suggests that 16% of the U.S. water utilities have very aggressive water, which might cause fibers to be released from asbestos cement pipe.

Even if the asbestos cement pipe is not attacked by the water some intermittent high concentrations may occur as a result of improper pipe tapping. Tapping asbestos cement pipe, that is, adding a service connection to the distribution pipe, requires that a hole be cut in the pipe. Some tapping devices allow debris from the cutting to fall into the pipe where it may remain in the water for some time depending on water flow. There are tapping devices now available that flush the debris from the pipe and thus prevent the contamination of drinking water with fibers.

Table 1. Distribution of reported asbestos concentrations in drinking water from 406 cities in 47 states, Puerto Rico, and the District of Columbia.

Highest asbestos concentration, 10^6 fibers/l.	Number of cities	Percentage
Below detectable limits	117	28.8
Not significant (< 0.5)	103	25.4
< 1	113	27.8
1-10	33	8.1
> 10	40	9.9
Total	406	100

Fiber Size of Asbestos in Water

Methods of sizing asbestos fibers in environmental samples have not been standardized. It is generally recognized that asbestos fibers found in water are smaller than the resolving power of the light microscope techniques (*18*). Little waterborne asbestos fiber size data have been determined with the scanning electron microscope because problems in resolving the very thin, small chrysotile fibrils make it difficult to use the scanning electron microscope in routine water analysis. Some water sample preparation methods used for transmission electron microscopy such as the rubout technique (*3, 4*) deliberately destroy the particle size distribution and only allow mass concentrations to be determined. Thus, to provide fiber size distribution data on drinking water samples, only direct transfer preparation methods with transmission electron microscopy are used.

Thousands of fibers have been measured in samples of drinking water analyzed according to the methods described in the EPA Preliminary Interim Procedure for Fibrous Asbestos (*19*). Over 7800 waterborne asbestos fibers were measured in conjunc-

Table 2. Available data on asbestos concentrations in United States water supplies determined by transmission electron microscopy.

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/l.)[a]	References	Comments
AK	Anchorage	1	< 1	(6)	
AK	Fairbanks	1	BDL	(6)	Below detectable limits
AL	Abbeville	2	NS	(6)	Not significant
AL	Birmingham	1	BDL	(6)	
AL	Montgomery	2	< 1	(6)	
AL	Tuscaloosa	2	< 1	(6)	
AR	Jonesboro	1	NS	(6)	
AR	Little Rock	1	< 1		
AR	Van Buren	1	> 10	(7)	At A/C pipe Co. probable sample contamination
AZ	Yuma	1	< 1	(6)	
CA	Alameda Co.	5	< 1	(8, 9)	
CA	Albany	3	< 1	(8)	
CA	Antioch	3	< 1	(8)	
CA	Atascadero	1	< 1	(6)	
CA	Atherton	1	BDL	(8)	
CA	Atwater	1	NS	(6)	
CA	Belmont	5	< 1	(8)	
CA	Berkeley	12	< 1, 1-10	(8)	
CA	Bollman	9	< 1	(8)	
CA	Broadmore	1	< 1	(8)	
CA	Burlingame	5	> 10	(8)	
CA	Castro Valley	1	< 1	(8)	
CA	Chabot	1	< 1	(8)	
CA	Clay	1	BDL	(10)	Raw in reservoir
CA	Clayton	2	BDL	(8)	
CA	Concord	4	< 1	(8)	
CA	Contra Costa Co.	7	> 10	(8)	
CA	Crystal Spring	4	> 10	(8)	
CA	Daly City	5	1-10, > 10	(8)	
CA	Danville	1	< 1	(8)	
CA	E. Palo Alto	3	< 10	(8)	
CA	El Sorbrante	2	BDL	(8)	
CA	Emeryville	1	< 1	(8)	
CA	Folsom	1	BDL	(10)	Raw south canal
CA	Foster City	4	1-10, > 10	(8)	
CA	Fremont	4	< 1	(8)	
CA	Hallard	3	1-10	(8)	
CA	Hayward	7	1-100	(8)	
CA	Hillsborough	2	> 10	(8)	
CA	LaFayette	2	< 1	(8)	
CA	Los Angeles	1	NS	(6)	
CA	Marin	36	< 1-100	(8)	
CA	Martinez	4	< 1	(8)	
CA	Mauseleium	1	BDL	(8)	
CA	Menlo Park	4	< 1	(8)	
CA	Merced	2	NS	(6)	
CA	Millbrae	8	1-50	(8)	
CA	Newark	1	< 1	(8)	
CA	North Marin	4	1-10	(8)	
CA	Oakland	16	< 1	(8)	
CA	Old River	2	> 10	(8)	
CA	Orinda	8	< 1	(8)	
CA	Pacifica	3	< 1	(8)	
CA	Patterson	1	1-10	(8)	
CA	Piedmont	1	< 1	(8)	
CA	Pindle	1	< 1	(8)	
CA	Pittsburg	1	< 1	(8, 7)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/l.)[a]	References	Comments
CA	Pleasant Hill	2	1	(8)	
CA	Pleasonton	4	1-10	(8)	
CA	Redding	6	< 1	(7)	
CA	Redwood	9	< 1	(8)	
CA	Richmond	1	< 1	(8)	
CA	S. San Francisco	7	< 1	(8)	
CA	Sacramento	1	NS	(8)	
CA	San Andreas	6	< 1	(8)	
CA	San Bruno	6	< 1-10	(8)	
CA	San Carlos	5	1-20	(8)	
CA	San Francisco	91	< 1-100	(8)	
CA	San Joaquin	4	< 1	(8)	
CA	San Jose	1	< 1	(8)	
CA	San Leandro	8	< 1-2	(8)	
CA	San Louis Obispo	1	BDL	(6)	
CA	San Mateo	8	< 1-50	(8)	
CA	San Pablo	3	< 1	(8)	
CA	San Ramon	2	< 1	(8)	
CA	Sobrante	8	BDL-2	(8)	
CA	Stanislaus River	1	BDL	(10)	
CA	Trinity River	1	BDL	(10)	
CA	Walnut Creek	7	< 1	(10)	
CA	Weaverville	4	1-10	(7)	
CO	Boulder	1	BDL	(6)	
CO	Denver	14	NS	(6, 9)	
CT	Ansonia	2	NS	(6)	
CT	Avon	8	< 1	(6)	
CT	Beacon Falls	1	BDL	(6)	
CT	Berlin	4	NS	(6)	
CT	Bloomfield	9	NS	(6)	
CT	Branford	1	BDL	(6)	
CT	Bridgeport	7	< 1	(6)	
CT	Bristol	1	NS	(6)	
CT	Brookfield	18	< 1	(6)	
CT	Brooklyn	2	NS	(6)	
CT	Burlington	2	NS	(6)	
CT	Canton	2	NS	(6)	
CT	Cheshire	1	NS	(6)	
CT	Clinton	5	NS	(6)	
CT	Colchester	3	BDL	(6)	
CT	Columbia	2	BDL	(6)	
CT	Coventry	10	NS	(6)	
CT	Cromwell	4	BDL	(6)	
CT	Danbury	11	BDL-NS	(6)	
CT	Darien	2	< 1	(6)	
CT	Deep River	1	NS	(6)	
CT	Derby	1	NS	(6)	
CT	East Haddam	1	NS	(6)	
CT	East Hartford	1	BDL	(6)	
CT	East Haven	1	BDL	(6)	
CT	East Lyme	5	< 1	(6)	
CT	East Windsor	2	BDL	(6)	
CT	Ellington	5	< 1	(6)	
CT	Enfield	4	NS	(6)	
CT	Farmington	8	< 1, 10	(6)	
CT	Glastonbury	2	NS	(6)	
CT	Granby	2	NS	(6)	
CT	Greenwich	3	BDL	(6)	
CT	Griswold	3	< 1	(6)	
CT	Groton	6	< 1	(6)	
CT	Guilford	2	NS	(6)	
CT	Hamden	4	NS	(6)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/l.)[a]	References	Comments
CT	Kent	1	BDL	(6)	
CT	Killingly	6	BDL	(6)	
CT	Ledyard	10	< 1	(6)	
CT	Litchfield	2	NS	(6)	
CT	Manchester	4	BDL	(6)	
CT	Mansfield	4	NS	(6)	
CT	Marlborough	2	BDL	(6)	
CT	Meriden	2	NS	(6)	
CT	Middlebury	2	< 1, 1	(6)	
CT	Middletown	2	BDL	(6)	
CT	Monroe	2	< 1	(6)	
CT	Montville	9	< 1	(6)	
CT	Morris	1	BDL	(6)	
CT	Naugatuck	5	BDL	(6)	
CT	New Britain	2	< 1	(6)	
CT	New Canaan	2	NS	(6)	
CT	New Fairfield	7	NS	(6)	
CT	New Hartford	3	NS	(6)	
CT	New Haven	6	NS	(6)	
CT	New London	2	NS	(6)	
CT	New Milford	11	< 1	(6)	
CT	Newington	1	BDL	(6)	
CT	Newtown	5	< 1,1	(6)	
CT	Norfolk	2	< 1	(6)	
CT	North Branford	2	BDL	(6)	
CT	North Canaan	3	< 1	(6)	
CT	North Haven	2	BDL	(6)	
CT	North Stonington	2	NS	(6)	
CT	Norwalk	4	NS	(6)	
CT	Norwich	7	< 1	(6)	
CT	Old Lyme	2	NS	(6)	
CT	Old Saybrook	1	NS	(6)	
CT	Orange	1	BDL	(6)	
CT	Plainfield	6	NS	(6)	
CT	Plainville	2	BDL	(6)	
CT	Plymouth	2	< 1	(6)	
CT	Portland	2	NS	(6)	
CT	Prospect	1	< 1	(6)	
CT	Putnam	1	BDL	(6)	
CT	Ridgefield	6	< 1	(6)	
CT	Salisbury	2	BDL	(6)	
CT	Seymour	2	NS	(6)	
CT	Sharon	2	BDL	(6)	
CT	Simsbury	5	< 1	(6)	
CT	Somers	4	BDL	(6)	
CT	South Windsor	5	BDL	(6)	
CT	Southbury	4	BDL	(6)	
CT	Southington	4	BDL	(6)	
CT	Sprague	2	< 1-2	(6)	
CT	Stafford	3	NS	(6)	
CT	Stamford	2	BDL	(6)	
CT	Stonington	5	NS	(6)	
CT	Stratford	6	BDL-6	(7)	Dist. at Asbestos Co.
CT	Suffield	1	BDL	(6)	
CT	Thomaston	2	BDL	(6)	
CT	Thompson	3	NS	(6)	
CT	Tolland	13	< 1	(6)	
CT	Torrington	2	BDL	(6)	
CT	Vernon	6	< 1	(6)	
CT	W. Hartford	2	NS	(6)	
CT	Wallingford	2	NS	(6)	
CT	Washington	5	BDL	(6)	
CT	Waterbury	2	BDL	(6)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/l.)[a]	References	Comments
CT	Waterford	1	BDL	(6)	
CT	Watertown	1	NS	(6)	
CT	West Haven	1	NS	(6)	
CT	Westbrook	1	NS	(6)	
CT	Westport	2	BDL	(6)	
CT	Wilmington	1	NS	(6)	
CT	Winchester	1	BDL	(6)	
CT	Windham	2	BDL	(6)	
CT	Windsor Locks	2	NS	(6)	
CT	Woodbridge	2	NS	(6)	
CT	Woodbury	2	NS	(6)	
DC	Washington	3	< 1	(6)	
DE	Wilmington	1	< 1	(6)	
FL	Bonita Springs	1	BDL	(6)	
FL	Cape Coral	1	BDL	(6)	
FL	Fort Lauderdale	1	NS	(6)	
FL	Fort Myers	4	< 1	(6)	
FL	Lakeland	12	1-20	(6)	
FL	Lehigh Acres	1	NS	(6)	
FL	Melbourne	1	NS	(6)	
FL	Miami	1	BDL	(6)	
FL	Pensacola	45	1-40	(6)	Improved treatment, now low counts
GA	Atlanta	9	Intermittent	(6, 9)	
GA	Augusta	2	< 1	(6)	
GA	Savannah	3	BDL	(6)	
GA	Skidaway Is.	3	BDL	(6)	
IA	Corralville	1	BDL	(6)	
IA	Iowa City	1	BDL	(6)	
ID	Caldwell	2	NS	(6)	
ID	Nampa	2	NS	(6)	
IL	Cairo	1	NS	(6)	
IL	Champaign	2	NS	(6)	
IL	Chicago	218	< 1	(6,7,11,12)	
IL	Kankakee	1	BDL	(9)	
IL	Rantoul	1	BDL	(6)	
IN	Elkhart	1	BDL	(6)	
IN	Ft. Wayne	1	BDL	(6)	
IN	Goshen	1	BDL	(6)	
IN	Indianapolis	1	< 1	(6)	
IN	Lake Michigan	1	BDL	(6)	
KS	Hutchinson	2	BDL	(6)	
KS	Johnson County	2	BDL	(7)	
KS	Kansas City	3	NS	(6, 7)	
KS	South Hutchinson	1	NS	(6)	
KS	Topeka	1	NS	(6)	
KY	Ashland	1	BDL	(6)	
KY	Covington	2	BDL	(6)	
KY	Danville	6	> 10	(6)	
KY	Frankfort	3	BDL	(6)	High count in raw water
KY	Harrodsburg	2	1-20	(6)	
KY	Herrington Lake	1	> 10	(6)	
KY	Irving	1	NS	(6)	
KY	Ky Dam Village	1	> 10	(6)	
KY	Lexington	1	BDL	(6)	
KY	Louisville	1	NS	(6)	
KY	Ludlow	1	NS	(6)	
KY	Murray	2	NS	(6)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/L)[a]	References	Comments
KY	Nicholasville	1	1-10	(6)	
KY	North Marshall	1	NS	(6)	
KY	Ohio River	1	BDL	(*10*)	
KY	Taylorsville	1	> 10	(6)	
LA	New Orleans	6	> 1	(6, *7*)	
MA	Amherst	8	> 1	(6)	
MA	Billerica	1	BDL	(9)	
MA	Boston	17	NS	(6, 9)	
MA	Chicopee AFB	7	1-10	(6)	
MA	Springfield	1	1 < 1	(6)	
MD	Baltimore	6	< 1	(6)	
MD	Potomac	2	BDL	(6)	
MD	Rockville	2	NS	(6)	
MD	Swanson's Creek	1	BDL	(*10*)	Raw water
ME	Portland	3	NS	(6)	
MI	Bay City	1	1	(*13*)	
MI	Eagle Harbor	8	< 1	(6)	
MI	Iron River	1	1-10	(6)	
MI	Marquette	4	< 1	(6)	
MI	Midland	1	< 1	(*13*)	
MI	Ontonagon	5	< 1	(*13*)	
MN	Beaver Bay	14	> 10	(*13*)	
MN	Cloquet	1	NS	(6)	
MN	Duluth	134	> 10 < 1	(5, 6, *13*)	After filtration (1977)
MN	Grand Marais	9	< 1	(6)	
MN	Silver Bay	16	1-10	(6)	
MN	Two Harbors	33	> 10	(6)	
MO	Independence	2	< 1	(6)	
MO	Kansas City	3	< 1	(6, 9)	
MO	Springfield	1	< 1	(6)	
MO	St. Louis	12	NS	(6)	
MS	Jackson	3	< 1	(6)	
MT	Billings	1	BDL	(6)	
MT	Laurel	1	BDL	(6)	
NC	Durham	5	1	(6)	
NC	Fayetteville	2	NS	(6)	
MC	Marshville	2	NS	(6)	Possible contamination
NH	Merrimac River	2	1-2	(6)	Raw water
NJ	Boundbrook	3	1-4	(6)	Raw water
NJ	Elizabeth	2	BDL	(6)	
NJ	Jersey City	1	< 1	(6)	
NJ	Manville	6	BDL	(7)	
NM	Albuquerque	4	BDL-3	(*14*)	
NM	Algodones	1	> 10	(*14*)	
NM	Belen	5	BDL	(*14*)	
NM	Kelly Ranch	1	> 10	(*14*)	
NM	Las Cruces	4	BDL	(*14*)	
NM	Pojoaque	1	> 10	(*14*)	
NM	Rio	3	BDL	(*14*)	
NM	Santa Fe	2	> 10	(*14*)	
NM	Socorro	13	NS-> 10	(6, *14*)	Most recent data shows NS
NM	Truth or Consequences	3	BDL	(*14*)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration ($\times 10^6$ fibers/L)[a]	References	Comments
NY	Buffalo	2	< 1	(6)	
NY	Elmira	1	NS	(6)	
NY	Glen Falls	1	BDL	(6)	
NY	Little Falls	2	< 1	(6)	
NY	Long Island	1	< 1	(10)	Raw well
NY	E. Islip	2	< 1	(6)	
NY	Mt. Kisco	1	NS	(6)	
NY	New York	13	BDL	(6, 9)	
NY	Niagara Falls	2	< 1	(6, 9)	
NY	Oswego	2	NS	(6)	
NY	Rochester	2	NS	(6)	
OH	Barberton	3	NS	(6)	Raw water
OH	Cincinnati	2	NS	(6)	
OH	Clyde	1	BDL	(6)	
OH	Dayton	1	NS	(6)	
OH	Fairborn	1	BDL	(6)	
OH	Kent	1	BDL	(6)	
OH	Lake Erie	1	BDL	(10)	Raw water
OH	Marietta	1	NS	(6)	
OH	Milford	1	NS	(6)	Cistern
OH	Northridge	18	NS	(6)	
OH	Scioto River	1	BDL	(10)	Raw water
OH	Sidney	4	BDL	(6)	
OH	Xenia	1	BDL	(6)	
OK	Muskogee	1	BDL	(6)	
OK	Tulsa	1	BDL	(6)	
OK	Verigris River	1	BDL	(10)	Raw water
OR	Newport	3	< 1	(6)	
PA	Bethlehem	1	NS		
PA	Conemaugh River	1	BDL	(10)	Raw water
PA	Crooked Creek	1	BDL	(10)	Raw water
PA	Delaware River	1	BDL	(10)	Raw water
PA	Erie	5	< 1	(6, 7)	
PA	New Chester	1	BDL	(6)	
PA	Ohio River	1	BDL	(10)	Raw water
PA	Paint	6	1-20	(6)	
PA	Philadelphia	52	Intermittent	(6, 7)	
PA	South Pittsburg	1	< 1	(6)	
PA	Susquehanna River	2	BDL	(10)	Raw water
PA	Two-Lick Creek	1	BDL	(10)	Raw water
PR	San Juan	1	NS	(6)	
RI	Newport	3	< 1-1	(6)	
SC	Anderson	5	BDL	(6, 7)	
SC	Bishopville	7	> 10	(6)	
SC	Camden	1	> 10	(6)	
SC	Columbia	1	< 1	(6)	
SC	Douglas-Due West	1	> 10	(6)	
SC	Greenville	7	BDL	(6)	
SC	Greenwood	13	1-10	(6)	
SC	N. Charleston	4	BDL	(6)	
SD	Lead	3	BDL	(7)	
TN	Chattanooga	5	BDL-5	(6, 7)	
TN	Clarksville	1	< 1	(6)	
TN	Nashville	2	< 1	(6)	
TX	Abilene	1	BDL	(6)	
TX	Amarillo	1	< 1	(6)	
TX	Austin	3	NS	(6)	

Table 2 (cont'd).

State	City	Number of samples	Asbestos concentration (× 10^6 fibers/L)*	References	Comments
TX	Cleburne	16	< 1	(6)	
TX	Dallas	2	BDL	(9)	
TX	Houston	10	NS	(6, 15)	
TX	Lockhart	15	< 1	(6)	
TX	San Antonio	2	NS	(6)	
TX	Wichita Falls	1	BDL	(6)	
VA	Charlottesville	1	NS	(6)	
VA	Chesapeake	14	NS	(6)	At hydrants >10
VA	Reston	1	BDL		
VI	St. Croix	4	> 10	(6)	Cisterns
VT	Battleboro	1	< 1	(6)	
VT	Crystal Springs	1	< 1	(6)	
VT	E. Newburg	1	NS	(6)	
VT	Eden	1	< 1	(6)	
VT	Jericho	1	NS	(6)	
VT	North Troy	2	1-2	(6)	
VT	Quarry Hill	1	NS	(6)	
VT	Richmond	1	NS	(6)	
WA	Aberdeen	1	NS	(6)	
WA	Anacortes	1	BDL	(6)	
WA	Bremerton	1	> 10	(6)	
WA	Everett	7	> 10	(6)	
WA	Hoquiam	1	BDL	(6)	
WA	Levinworth	1	1-10	(6)	
WA	Lynden	2	1-10	(6)	
WA	Olympia	1	BDL	(6)	
WA	Seattle	44	> 10	(6)	
WA	Tacoma	2	BDL	(6)	
WA	Tumwater	1	NS	(6)	
WA	Yakima	2	NS	(6)	
WI	Appleton	2	< 1	(6)	
WI	Ashland	14	1-10	(6)	
WI	De Pere	1	< 1	(6)	
WI	Eau Claire	1	BDL	(6)	
WI	Fond Du Lac	3	< 1	(6)	
WI	Kaukauka	1	NS	(6)	
WI	La Crosse	1	BDL	(6)	
WI	Little Chute	1	BDL	(6)	
WI	Manitowoc	1	< 1	(6)	
WI	Marinette	1	< 1	(6)	
WI	Menasha	1	< 1	(6)	
WI	Neenah	1	< 1	(6)	
WI	Neopit	1	< 1	(6)	
WI	New London	1	BDL	(6)	
WI	No. Fond Du Lac	2	< 1	(6)	
WI	Platteville	1	< 1	(6)	
WI	Port Edwards	1	< 1	(6)	
WI	Sheboygan	1	< 1	(6)	
WI	Sturgeon Bay	1	< 1	(6)	
WI	Superior	17	1-10	(6, 16)	
WI	Two Rivers	1	< 1	(6)	
WI	Union Center	1	< 1	(6)	
WV	Huntington	1	< 1	(6)	
WV	Wheeling	1	NS	(6)	
WY	Cheyenne	2	0.1-1	(6)	

*BDL = Below detectable limits of the method (no fibers were found); NS = too few fibers were found to allow an accurate concentration value (usually NS corresponds to a count less than 0.5 × 10^6 fibers per liter.

Table 3. Some size characteristics of asbestos fibers found in various water supplies.

Source	Type of fiber	Number of fibers measured	Average length, μm	Average width, μm	Average aspect ratio[a]	Maximum length found μm
Reservoir with natural erosion (WA)	Chrysotile	200	0.8	0.050	25:1	5
Reservoir with natural erosion (CA)	Chrysotile	640	1.3	0.04	39:1	10
Cistern with asbestos tile roof (VI)	Chrysotile	342	2.3	0.04	62:1	25
Distribution sites from five asbestos cement pipe systems (SC, PA, FL)	Chrysotile	1440	4.3	0.068	121:1	80
Lake Superior (MN)	Amphibole	468	1.5	0.10	11:1	14

[a]Aspect ratio: Length/width.

tion with an epidemiology study in the San Francisco Bay Area, California. The average length and width of the chrysotile fibers were 1.4 and 0.040 μm, respectively. The lengths ranged from 0.1 to 59 μm. The fibers in the drinking water of this study area may have come from a variety of sources including natural erosion of serpentine rock, pollution from the wastes of asbestos manufacturing and possibly corrosion of asbestos cement pipe.

The data presented in Table 3 suggest that the fiber size distribution in the drinking water is dependent on the source of the fibers. It is apparent that the corrosion of asbestos cement pipe when attacked by aggressive water can contribute a greater proportion of long fibers than does the natural erosion of a serpentine rock formation. The distribution of fiber lengths described in Table 4 shows that fibers from asbestos cement pipe systems tend to be longer than naturally occurring fibers such as are found in California and Washington State. Statistical analysis of the fiber size distribution before and after asbestos-cement pipe length in California showed that the fiber set in the water before the pipe had a higher proportion of shorter fibers than the fiber set after the pipe (20). The sample taken before the asbestos cement pipe contained fibers presumably from natural erosion; the sample taken after the pipe presumably contained both the natural erosion fibers and some from the pipe.

Table 5 presents some data on aspect ratio (length/width) which also reflect the size differences between the fibers in various drinking waters. It is evident even in the cases where the source is natural erosion that the vast majority of the chrysotile fibers exceeds a 10:1 aspect ratio.

Variation in Concentration and Size Data

In the natural system the weather plays an important part in varying the concentration of asbestos fibers in water over time. Cook (5) has shown at least a fivefold increase in an amphibole fiber concentration in drinking water as a result of a storm. The erosion of natural serpentine rock and of asbestos waste piles undoubtedly increases or decreases depending on rainfall and stream flow. Asbestos concentrations in asbestos cement pipe are known to be increased temporarily 10- or 100-fold by pipe tapping and are probably affected by water flow rates and changes in water chemistry and temperature.

Differences in methodology for analyzing asbestos

Table 4. Distribution of fiber lengths in various water supplies.

Source	Number of fibers	Distribution of fiber length classification (%)									
		<0.1 μm	0.1-0.2 μm	0.2-0.5 μm	0.5-1.0 μm	1-2 μm	2-5 μm	5-10 μm	10-25 μm	25-50 μm	> 50 μm
Reservoir water (WA)	210	0	0	33	51	14	2	0	0	0	0
Raw water (CA)	240	0	0	6	28	46	17.5	2	0.5	0	0
Asbestos cement pipe system (FL)	505	0	0	5	17	30	34	13	2	1	0
Asbestos cement pipe system (SC)	215	0	0	23	16	23	16	14	6	1	1
Cistern (VI)	342	0	0	9	31	32	19	4	5	0	0

Table 5. Distribution of fiber aspect ratios in various water supplies

Source	Number of fibers	Distribution of fiber aspect ratio (%)				
		3–<5	5–<10	10–<100	100–<500	≥500
Reservoir water (WA)	210	1	7.4	91.6	0	0
Raw water (CA)	240	2	6	89	4	0
Asbestos cement pipe system (FL)	503	1	3	76	19	1
Asbestos cement pipe system (SC)	215	6	3.5	67	20	3.5
Cistern (VI)	342	1	16	77	5	1

samples can also contribute to the variation in reported asbestos concentrations. The Nuclepore Jaffe Wick technique (*21*) for sample preparation has been shown to provide good interlaboratory comparison data. Laboratories using this method have reported results within a factor of two and it is gaining acceptance as the most widely used method.

Differences in methodology for preparing samples for sizing can lead to differing size characterizations of the same sample. Three laboratories determined the fiber length distribution for the Union Internationale Contre le Cancer (UICC) Amosite standard reference material. The data are given in Table 6. It is evident that while Laboratories 1 and 2 found the fibers to be 40-60% under 1 μm, Laboratory 3 found only 7% less than 1 μm.

In environmental water sampling the water is filtered through a 0.1 micrometer pore size Nuclepore filter. A section of the filter is attached to a glass slide and a deposit of carbon evaporated onto the particulates and filter. A small section is cut and placed on an electron microscope grid. The filter is dissolved by using a modified Jaffe wick apparatus (*22*), leaving the particulates embedded in the carbon film on the grid. When possible, photographs are taken of random fields at 1000x and 500x magnification. Fiber lengths and diameters are measured with a 7-power measuring eyepiece on enlargements representing 3,000x and 15,000x magnification. In many water samples, however, interfering debris does not allow the fibers to be concentrated on a filter so that several fibers are present in each field of view. Often many fields of view must be searched to find one fiber. In these situations fibers are measured by aligning them with marks or circles inscribed on the fluorescent microscope screen. Replica gratings are used to determine the exact magnification at the screen's surface.

Samples which contain a number of long fibers are difficult to handle. In some cases grids with larger mesh size are used. When a fiber overlaps a grid bar, a switch from the transmission to the scanning mode allows the analyst to follow the fiber to its end.

Conclusions

Based on the available data on waterborne asbestos it is concluded that the majority of U.S. water consumers are not exposed to constant concentrations of asbestos fibers above 1×10^6 fibers per liter. In some areas, however, people are exposed to concentrations of asbestos fibers between 1 and 100 $\times 10^6$ million fibers per liter from natural erosion, pollution, or corrosion of asbestos materials such as asbestos cement pipe or roofing material.

The sizes of asbestos fibers in drinking waters differ depending on the source of the fibers. Fibers contributed by natural erosion are generally shorter than those contributed by asbestos cement pipe.

The use of a specific manufacturer's name is for identification purposes only and does not constitute endorsement by the U.S. Environmental Protection Agency.

Table 6. Distributions of fiber lengths for UICC Standard Reference Amosite by three laboratories using three different techniques.

Method	Distribution of length classifications (%)									
	< 0.2 μm	0.2-0.5 μm	0.5-1.0 μm	1-2 μm	2-5 μm	5-10 μm	10-25 μm	25-50 μm	50-100 μm	> 100 μm
Rendall (*23*)	—	23	31.1	25.5	14.7	4.4	1.08	0.16	0.03	0.02
ITTRI Method (*24*)	—	24.6	17.0	22.4	22.9	7.0	3.7	3.1	0.4	0.01
Brown et al. (*25*)	—	7.0		20	40	16	15	1.5	0.5	0.0

The authors wish to acknowledge the work of Mr. Arthur F. Hammonds, Epidemiological Branch of the Health Effects Research Laboratory, with the computer programs necessary for storing and retrieving the waterborne asbestos analysis data. A complete discussion and listing of the data used to develop Table 1 is to be published as an Environmental Protection Agency, Office of Research and Development Technical Research Report entitled, "Exposure to Asbestos from Drinking Water in the United States."

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Comments on "Concentration and Size of Asbestos in Water Supplies"

William E. Smith (*Fairleigh-Dickinson Univ., Madison, N.J. 07940*): Findings of fibers in water supplies bring up the question of whether they present any hazard to people drinking the water. To develop experimental information on this question, we maintained 600 hamsters from the age of about two months throughout their lives on drinking water with and without addition of some mineral fibers.

We found some tumors that may be related to treatment in hamsters that drank water containing fibers of naturally crystallized amosite asbestos from South Africa. No tumors attributed to treatment occurred in hamsters that drank water containing tailings from milling of taconite ore rich in cummingtonite/grunerite mineralogically related to amosite.

Since carcinogenicity of mineral fibers has been related to their dimensions by results of intrapleural injections in experimental animals, it is of interest to look at dimensions of fibers in our drinking water exposures.

In considering dimensions of fibers, I was glad to see that Dr. Millette's data did not show merely mean dimensions. Mean dimensions were not impressively different in our sample of amosite as compared to our samples of tailings as measured by electron microscopy at 2500×. However, differences in fiber length distributions were obvious, as better seen in measurements at 600×, which show that the percent of fibers longer than 10 μm was 14% in the amosite as compared to 4% in the tailings. Among fibers measured as longer than 10 μm, 25% were longer than 20 μm in the amosite; none were longer than 20 μm in the tailings.

Following Dr. Millette's paper, a question was asked as to how mineral fibers were suspended in water to assure ingestion by animals. I responded as follows:

To maintain suspension of insoluble mineral fibers in water, and thus assure their ingestion by animals drinking the water, we designed drinking fountains in which the water was put in funnels and agitated with a stream of air. We described this method in a paper last year [Am. Ind. Hyg. Assoc. J. 39: 583 (1978)].